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Effectiveness of 3D Printing in Small Scale Production

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The purpose of this thesis is to estimate the effectiveness of two 3D printing methods (fused deposition modeling and stereolithography) for prototyping and small-scale production at a 3D printing laboratory at Metropolia University of Applied Sciences.

The 3D printing technology is currently developing, so not much literature is available yet. That is the reason why before actual production a thorough analysis is needed of the advantages and disadvantages and of the effectiveness of the equipment and printing methods for the chosen purpose.

This thesis suggests that 3D printing is an efficient method for prototyping and small-scale production. The effectiveness of two different methods of 3D printing is compared. 3D printers and one handheld 3D scanner were used for prototyping and production projects.

The fused deposition modeling printer was suitable only for familiarizing with the 3D printing process, not for prototyping. Stereolithographic printers are better used in prototyping. However, the process was slow and required long preparation and observation due to many unsuccessful attempts. The prototypes were not always working. The 3D scanner was suitable only for non-reflecting materials.

In conclusion, it seems that at the moment 3D printing prototyping is suitable for only custom projects requiring this specific technology. For other purposes the conventional technology still takes over.

Keywords	3D printing, additive manufacturing, 3D scanning

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Insinöörityön tarkoituksena oli arvioida 3D-tulostuksen tehokkuutta pienimuotoisessa tuotannossa ja prototyyppien valmistuksessa. Kahta eri 3D-tulostusmenetelmää oli käytetty tässä tutkimuksessa: fused deposition modeling ja stereolithography. Tämä tutkimus tapahtui Metropolia Ammattikorkeakoulun 3D-tulostuslaboratoriossa.

3D-tulostustekniikka kehittyy parhaillaan, joten monet teoreettiset materiaalit eivät ole vielä saatavilla. Tästä syystä, ennen varsinaista tuotantoa 3D-tulostusmenetelmät tarvitsevat perusteellista analyysia eduista ja haitoista. Tämän jälkeen 3D-tulostusmenetelmä tullaan valitsemaan tehokkuuden perusteella.

Tämä insinöörityö osoitti, että 3D-tulostus on tehokas menetelmä prototyyppien valmistuksessa ja pienimuotoisia tuotantoja varten. Kahden eri 3D-tulostustekniikan tehokuutta verrattiin. 3D-tulostimet ja yksi kannettava 3D-skanneri olivat käytössä prototyyppien ja tuotannon projekteissa.

Fused deposition modeling 3D-tulostustekniikka oli sopiva ainoastaan 3D-tulostusprosessiin tutustumiseen, eikä prototyyppien tekemisessä. Stereolithography 3D-tulostusmenetelmä toimii paremmin prototyyppien valmistuksessa. Kuitenkin tämä prosessi oli erittäin hidas, joka edellytti pitkää valmistelua ja tarkkailua. Tämä aiheutti monta epäonnistunutta 3D-tulostusta. Lisäksi prototyypit eivät aina toimineet. 3D-skanneri oli sopiva vain heijastamattomien materiaalien kanssa.

Johtopäätöksenä tällä hetkellä 3D-tulostus soveltuu vain yksittäisiin hankkeisiin, jotka edellyttävät erityistä tekniikkaa. Muihin tarkoituksiin perinteinen teknologia on edelleen voimassa.

Avainsanat	3D-tulostus, additiivinen tuotanto, 3D-skannaus

Contents

Abbreviations

3D	Three dimensional
4D	Four dimensional
ABS	Acrylonitrile butadiene styrene
AM	Additive manufacturing. 3D printing uses this process to build a component in layers by depositing material.
CLIP	Continuous liquid interface production
EBM	Electron beam melting
FAT	File allocation table. An older file system for storing and organizing computer files and data. Primary computer file system for various operation systems.
FDM	Fused deposition modeling
FPS	Frames per second. FPS counts how many unique consecutive images a camera can handle each second.
LED	Light-emitting diode
LOM	Laminated object manufacturing
NTFS	New technology files system. A newer file system for storing and organizing computer files and data. Intended for use in Windows system drives.
OBJ	Geometry description file format
PLA	Polylactic acid
PLY	Polygon file format is a format for storing graphical objects.
SLA	Stereolithography
SLM	Selective laser melting
SLS	Selective laser sintering
STL	Stereolithography file format

1 Introduction

3D printing was introduced to Media Engineering students during a course about hybrid media. At a certain point of the course, Aarne Klemetti, the lecturer, stated, “Printing technology is not only ink on paper, it is much more. All of you are going to witness this during the upcoming years.” This simple quote made me interested in the subject of 3D technology.

Since the beginning of 3D printing technology the additive manufacturing (AM) has been used for rapid prototyping. Advances in the 3D printing technology transferred 3D printing to a stage of rapid manufacturing. The most commonly used 3D printing methods are stereolithography and fused deposition modeling. My thesis is going to study these two methods closely. The methods stereolithography and fused deposition modeling are going to be analyzed and compared. The advantages and disadvantages of these methods are going to be explained. The purpose is to determine out how effective the 3D printing technology is in small scale production.

A 3D scanner was used in several experiments which were carried out in the final year project. The goal is to see how 3D scanning will speed up the manufacturing process, as proper digital 3D modeling takes days up to weeks. Digital 3D models can be very accurate, close to reality and, therefore, very illustrative which is an important point in engineering projects. Scanned objects are going to be printed out and their accuracy is going to be estimated too. This way it could be find out how applicable 3D scanned objects are for engineering prototyping.

With the knowledge gathered from experiments and analysis concerning stereolithography and fused deposition modeling, this final year project will guide students of Metropolia University of Applied Sciences on the Leppävaara campus in their projects connected with 3D printing and scanning.

The last practical part of the project was a manufacturing experiment. I am going to 3D model a lamp and manufacture it. As a result I want to make a working lamp using one of the 3D printing techniques. Moreover, the amount of work, time, and materials spent will help me to estimate the potential effectiveness of a small-scale 3D printing production. Also, future students can use the results of my thesis a guideline when choosing 3D printing for prototyping or production.

2 3D Printing

2.1 What Is 3D Printing

Theoretically, 3D printers work in a similar way to regular commercial printers, but in practice the 3D printing and commercial printing are totally different fields. Regular printers use ink and paper to produce text and images on a sheet of paper. 3D printers use, for example, thermoplastic and other different materials to create a real concept model. [1.]

Before printing a 3D model it should be designed in 3D software. The quality of the model depends entirely on the accuracy of the 3D model and the 3D printer. Also, it depends on the technique and the material a particular 3D printer uses, and how detailed the 3D model is that was made in 3D software. Recently, with new technological development, there has been an announcement on the next coming generation of 3D printers, 4D printers. [1.]

2.2 Brief History of 3D Printing

The starting point of 3D printing was in the 1980s. The very first solid model was made by Hideo Kodama of Nagoya Municipal Industrial Research Institute in 1982. The first working 3D printer was created in 1984 by Charles W. Hull of 3D Systems Corp. He patented his invention by the name of stereolithography (SLA). Three years later in 1987 Carl Deckard and Josepth Beaman invented a printing process called selective laser sintering (SLS). In the beginning of 1990s the very first 3D printer using stereolithography was produced. Later on new and more complex printing methods started to unravel for the manufacturing terms. [2.]

In the technologically developed world now there is a trend for progressive environmental ideas, such as 3D printers. Subtractive manufacturing was previously used in production, where the unneeded material was removed and thrown away. With additive manufacturing, only the necessary amount of material is used. As a result, the production is not producing wasteful garbage. Currently there are two types of 3D printers, commercial and personal ones. In developed countries simple personal 3D printers are sold freely, and commercial ones are now used for creating required parts. [3.]

2.3 Commercial 3D Printers and Personal 3D Printers

Commercial 3D printers have been in use for decades, since the technology started in 1980s. Previously commercial 3D printers were expensive and slow, which is the reason why companies did not use 3D printing in large–scale manufacturing. It was mainly used for prototyping in small proportions. Today companies are experimenting with different methods to produce the final product. Regarding the prices of commercial 3D printers, it has been estimated that the machines that cost from 15 to 20 thousand dollars in 2013, could cost as much as two thousand in the year 2016. [4.]

The same way as it happened to computers, the 3D printing technology have become cheaper and available to a wider audience. The price of 3D printers has evenly decreased in the years from 2010 to 2013. On today’s market, personal 3D printers typically are in the price range from 300 to 2000 dollars. Regular personal 3D printers use PLA and ABS materials. Polyactic acid (PLA) is made out of renewable resources. Acrylonitrile budadiene styrene (ABS) is a petroleum-based made plastic. The main difference between these two is that the ABS material is strong, flexible and has a high temperature resistance, when PLA has a wide range of available colors, translucencies and a glossy feel to it. ABS is chosen when a person wants his/her object to be durable and PLA is chosen for displacement purposes. [4.]

Even portable personal 3D printers came out to the market, such as portable Portabee with a price tag of 600 dollars. It is small in scale and has a good printing result. Portabee can produce both ABS and PLA models. [4.]

2.4 3D Printing Methods

Stereolithography was the first commercially available 3D printer. The UV laser beam draws out the 3D model one thin layer at a time, hardening that slice of the eventual 3D model as the light hits the resin. Materials that are used are epoxy polymers, both rigid and flexible. [1.]

Fused deposition modeling is one of the less expensive 3D printing methods. The majority of personal 3D printers uses this method. FDM extrudes thermoplastic layer-by-layer to create a physical model. The materials used are PLA (Poly Lactic Acid), Nylon and ABS (Acrylonitrile Butadiene Styrene). [1.]

Selective laser sintering works similarly to SLA, but uses powdered materials, such as polystyrene, ceramics, glass, nylon, and metals including steel, titanium, aluminium, and silver. [1.]

PolyJet photopolymer allows for various materials and colors to be incorporated into single prints, and at high resolutions. PolyJet can create modules with accuracy of a 0.1 mm of smooth surface. The technology is highly expensive. It was made and patented by the Stratasys company. [2.]

The creamy viscosity of **syringe extrusion** can be used in 3D printers equipped with syringe extruders. The materials could be clay, cement, silicone, and Play-Doh. Certain foods like chocolate, frosting, and cheese can also be printed with this system. [2.]

Other Significant Methods

Selective laser melting (SLM) fully melts the powder rather than just fusing the powder granules at a lower temperature. SLM is a perfect method for parts that require strength or temperature resistance. This method in result produces solid and strong parts. [2.]

In **laminated object manufacturing** (LOM) layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter. The LOM production process cost is comparatively low thanks to the materials it uses. However, it lacks dimensional accuracy. [2.]

In **electron beam melting** (EBM) layer-by-layer of metal powder is melted with an electron beam instead of a UV laser. EBM produces metal parts that are equal in strength to those that were manufactured on traditional machinery. [2.]

3 The Future Development of Additive Manufacturing

Continuous Liquid Interface Production

A company called Carbon3D announced their revolutionary technology Continuous Liquid Interface Production (CLIP) for 3D printing in the TED 2015 conference in Vancouver, Canada. Joseph DeSimone, CEO and Co-Founder of Carbon3D, stated, “Existing 3D printing, or additive manufacturing, technology is really just 2D printing, over and over again”. Due to this the whole process of 3D printing is generally slow and produce mechanically weak objects thanks to layer-type shape. With the CLIP technology the 3D printed object will be printed as a solid piece from the beginning to the end. [5.]

Conventional 3D printing style from the 1980s was the typical SLA technology. The object will be built layer by layer before it is done completely. What CLIP does is that it eliminates the pause and build technique entirely. [5.]

CLIP uses a radiation and power spectrum, which is safe for human eyes, for curing the resin, as typically SLA method does. The important new feature is the dead zone at the bottom of the resin tank, as figure 1 shows. Oxygen plays the main role in this process, as it is used as an inhibitor. There is no layering process. Typically one applies plastic to the base layer by layer, until the whole object is received. Subsequently, the platform is continually moving quietly up until the object is printed completely without any pauses. [5.]

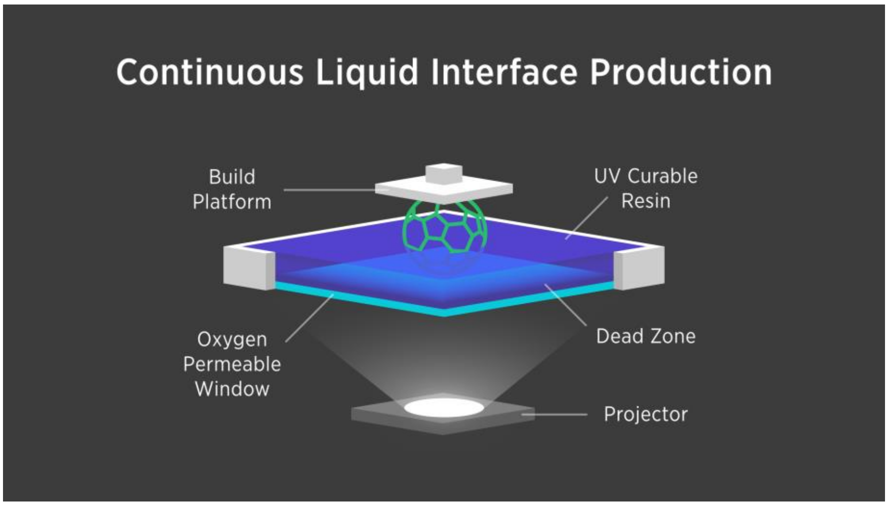

Figure 1. How CLIP works. Copied from Carbon3D [5].

In CLIP the model is printed from a resin tank with the speed up to 25 - 100 times quicker than in the SLA conventional 3D printing (see figure 2). [5]

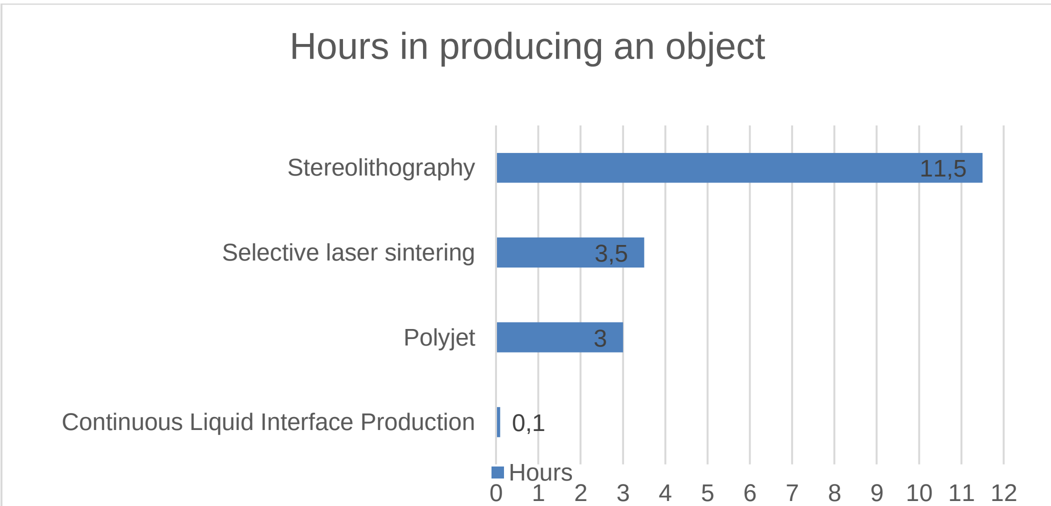

Figure 2. Hours in producing an object. Data gathered from Carbon3D CLIP 3D [6].

Under an electron microscope it can be clearly seen that CLIP and conventional 3D printing differ from one another in the molecule structure. CLIP has a solid object structure, while a 3D printed object built by layers has a wavy structure, as can be seen in figure 3. As result, the CLIP method not only produces faster, but also more durable products in the process.

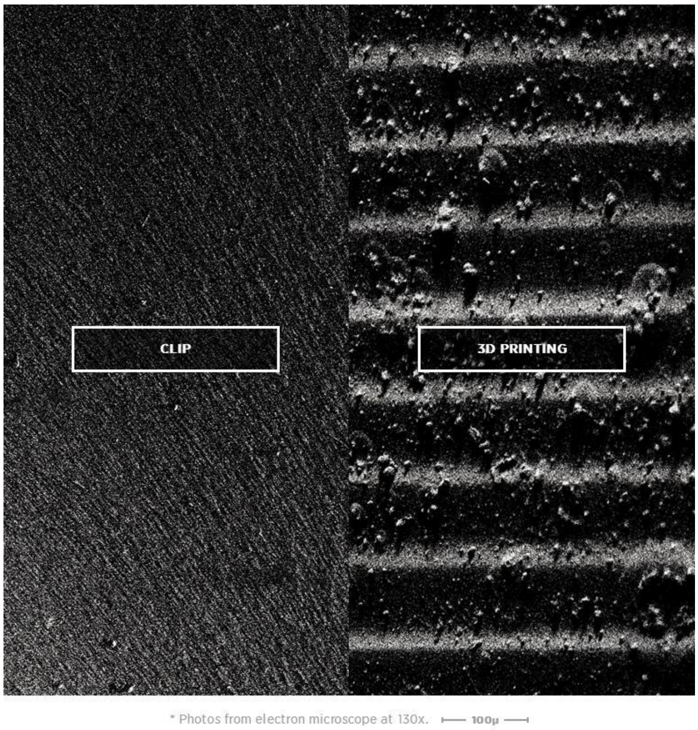

Figure 3. Electron microscope at 130x. Copied from Carbon3D unveils CLIP [6].

Conclusion

The new method of 3D printing CLIP will completely change the industry. No longer will the “layer-by-layer” approach be associated with 3D printing. The printing process will consist of one solid piece and not of several thousand pieces. It can be predicted that CLIP will most likely replace stereolithography entirely in the near future.

4D Printing

Some engineers in the field of AM are already 3D printing should be forgotten and that focus should be on 4D printing. 4D printing means 3D printing with functionalities, as figure 4 shows. With 4D printing we can produce a product that could interact with environment around it. 4D printing would be a shape shifting item. It is estimated that the first 4D printing products are to be used in water piping and infrastructural systems. In the future they are predicting that by using this buildings can be created that would change their shape in the time of an earthquake or a tsunami. As a result, lives would be saved, and buildings would be prevented from crumbling down. [7.]

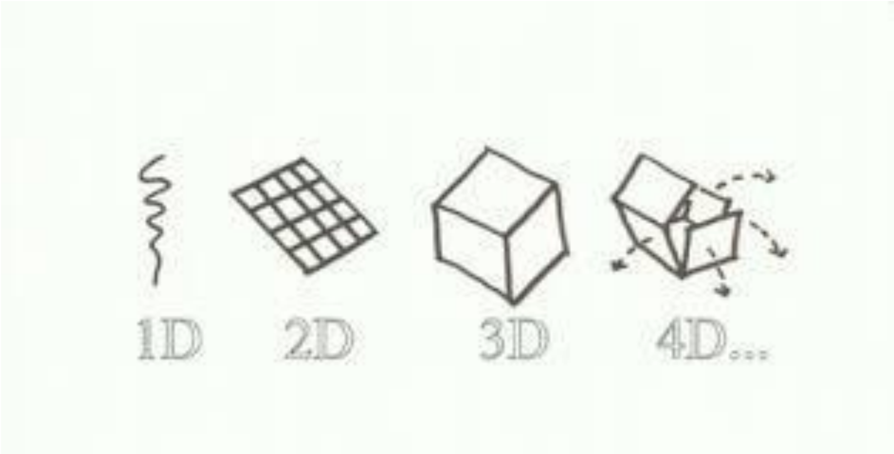

Figure 4. 4D printing. Copied from 4D printing [8].

4 3D Printing Lab at Leppävaara's Campus of Metropolia UAS

For a couple of years now, the Leppävaara campus of the Helsinki Metropolia University of Applied Sciences has owned only one 3D printer, namely Valmistaja 3000 developed by the Finnish company Suomen Laatujälki. The 3D printer is based on the fused deposition modeling technology for production of conventional 3D objects.

The Leppävaara campus of Metropolia also has its own small 3D printing laboratory. One of the 3D printers was Form 1+ by FormLabs (see figure 5). This device require the stereolithography technology. Moreover, the university obtained a CubePro Trio by Cubify printer (see figure 6). The printer has three extruders for 3-color printing. Essentially, a user can print a model with three colors simultaneously. Lastly, there is a handheld 3D scanner called Sense 3D in the laboratory. It was also manufactured by Cubify.

Figure 5.Form 1+. Copied from FormLabs [9].

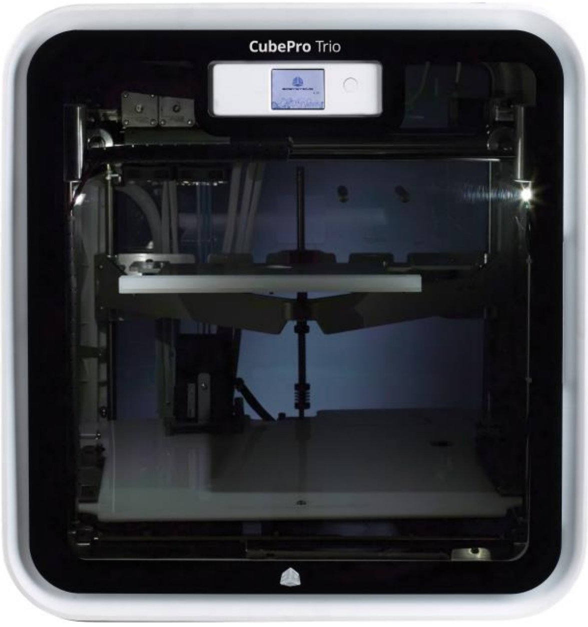

Figure 6. CubePro Trio. Copied from CubePro Trio 3D printer [10].

4.1 Comparing Fused Deposition Modeling to Stereolithography

Valmistaja 3000

The 3D printer Valmistaja 3000 was manufactured by Suomen Laatujälki, a Finnish company. The machine uses fused deposition modeling 3D printing technology. The materials are basic polymers: acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). These materials do not produce any harmful smoke. [1]

Before using the 3D printer, calibration should be performed. Leveling ruler is a must. The building platform must be perfectly leveled out before printing. Without this the end product will be uneven or deformed.

Valmistaja 3000 uses the Cura software. This software was developed by Ultimaker to change the .STL format into a readable .OBJ format for the 3D printers. [11] Basically what the Cura does is that it takes the model and slices it into layers which the machine will print later on. There is a primitive automatic supporting structures generator in the Cura software. Proper supporting structures should be built beforehand in 3D modeling software.

A piece of photopolymer paper should be placed on the building platform. This is done for not messing the build platform and for easy scraping off, as the building platform heats up to 135 degrees and the printed piece gets melded to the platform.

After printing the printed piece should be left on the platform for about two minutes for the heat to drop down. Later the photopolymer paper with the printed object should be taken off from the platform. Then the piece should be carefully ripped from the photopolymer paper.

The main problems experienced with the machine were burn marks and unevenness. The burn marks were caused by the nozzle, as it got heated up to 200 degrees, and at the time of finishing one layer and moving to another layer the nozzle would accidentally touch the surface of the previous layer. The building platform does not catch up with the nozzle and vice versa. This is the reason for the unevenness of objects that require much polishing later on.

Conclusion

Valmistaja 3000 is a good machine for learning the way how fused deposition modeling works in general. It is a good 3D extruder printer toy, but not a proper manufacturing machine.

Form 1+

The Form 1+ printer was developed by a young company called Formlabs. Form 1+ uses stereolithography method for printing. This is their second product, which is an enhanced version of the first Form 1. Form 1+ was upgraded in terms of printing quality, printing speed, and reliability of products. The material that it uses is liquid resin. The liquid resin is cured and transformed into a solid material by laser light.

Personal 3D printers are becoming more user-friendly. This can be seen with Form 1+. The setup of the 3D printers happens in less than 15 minutes. No calibration needed. No longer are SD cards or memory sticks required for transferring 3D model files into a 3D printer. A USB cable can now be connected from a 3D printer to a personal computer.

Moreover, now the 3D files can be in the stereolithography form (.STL). Thus, there is no need to convert the file into the object format (.OBJ). [12]

Formlabs have their own software, PreForm, for preparing Form 1+ for printing. The software is foolproof. There are five main icons in the software. The first icon is for changing the size of the model or models. The Z, Y and X-axes are locked. By changing one direction the size of the entire object can be changed. The second icon is for tilting the object in any direction. The third icon is generating support structures. The last, fourth, icon is for moving an object onto the building platform.

Before printing proper material, the right version of the material should be selected in the software. The user can place a support material in a location of their choice. A software generated location is also possible. The amount of resin is shown in milliliters in the section volume in PreForm. Also PreForm displays how many layers the machine will have to produce to make the whole model. The amount of time for printing the model is calculated in the software. The time will be also displayed on the led screen of the 3D printer.

The first two resin materials that came together with the 3D printer were clear and grey. Later it was noticed that the thickness of Form 1+ varies from material to material. For instance, clear has four different options of thickness. These are 0.2 mm, 0.1 mm, 0.05 mm and 0.025 mm. As for grey, there are only three options. They are 0.2 mm, 0.05mm and 0.025 mm.

There is a three step post production process with Form 1+. In the beginning, the just printed model should be carefully removed from the build platform. For this a putty knife comes in handy. In the pilling process the user will appreciate the designer’s idea of creating a small incursion in the pedestal for the putty knife.

Later, when the model is free from the build platform, it should be washed in an isopropyl bath. Two minutes for moving the model in the isopropyl tank are necessary, so that the alcohol can get in all the corners of a model. After this action the model should be left in the isopropyl tank for another ten minutes.

After the model is washed, the support structures should be removed from the model. For this action diagonal pliers should be used. Tweezers will also be handy. Small leftovers of support structures are better to clear with small tweezers than with bigger diagonal pliers.

While researching different ways of conducting a post curing procedure for the model, two different ways have been discovered. In the Aalto University Digital Design Laboratory a tank of water is used. The resin is sensitive to ultraviolet light, so leaving the model under sunlight or a UV lamp will do the same thing. Some practitioners even suggest leaving the model in a bowl of water under sunlight for ten minutes. [13]

The support structure should be carefully placed on the printed object. The PreForm software will automatically generate the supports, but complicated shapes require some adjustment. Advanced support structure settings have four options of altering the support structure. They are flat spacing, slope multiplier, base thickness and, lastly, height above base.

The first attempt of producing a quality print was a 3D model of the Eiffel tower. PreForm decided to import the file horizontally, to print it faster. The model was enlarged and rotated vertically. For this printing attempt automatically generated supports were chosen. For the resolution best quality was selected for printing, 0.025 mm. Material of choice was clear 02. It is a transparent and matte.

The printing time was eight hours. The post-production stage was tricky. The first try with the putty knife was quite an intimidating experience, as at one point the right hand holding the putty knife slipped cutting the rubber glove on the left arm. That little accident showed how important it is to be more attentive and cautious when working with sharp tools. Eventually the pilling of the Eiffel tower from the building platform was performed. After washing the tower in isopropanol, the cutting process of support structures started.

The result can be seen in figure 7. The red circles on the picture show the damaged surface that was harmed during the removing of the supports. With this attempt we got acquainted with the removal of support structures.

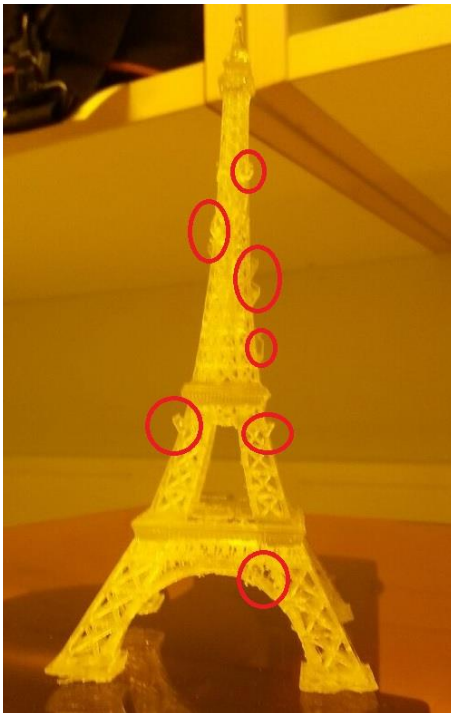

Figure 7. Damaged 3D printed Eiffel tower.

Basic shapes, for instance a small square-shape object, could be printed without support structures. We also printed out a companion cube from a popular video game called Portal2 (see figure 8). Printing simultaneously six of these cubes at the lowest quality (0.2 mm) took one hour and 50 minutes. The bottom of the companion cubes got a little deformed in the pilling process. However, in general the cubes were high level as shown in figure 8.

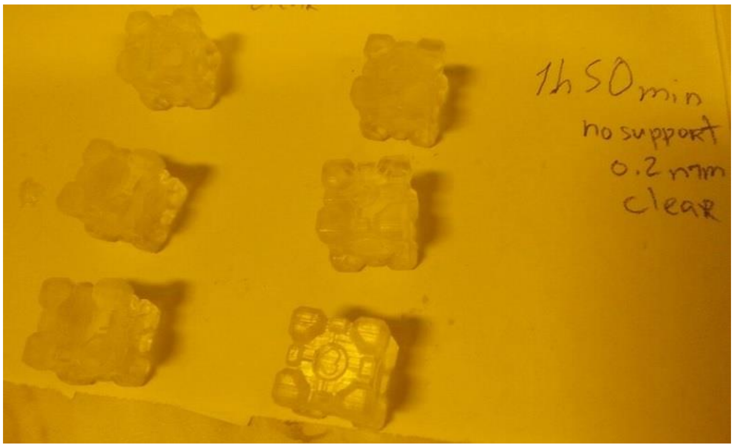

Figure 8. Six companion cubes.

Conclusion

Form 1+ is a user-friendly 3D printer. Preparing modules with PreForm is very easy. The machines is designed the way that even with small to none knowledge of 3D printing a great product could be still produced.

CubePro Trio

CubePro Trio was designed and manufactured by a company called 3D Systems. The company owner Chuck Hull is credited for inventing the process of 3D printing in the early 1980s. [1.]

The preparing phase for the printing of CubePro Trio was longer than expected, althought everything necessary for printing came along with Cubify Trio. There was a manual how to unpack the printer and how to make it functional. The entire list of items that were received: a tool box set, a memory stick of 2 GB with 3D design software, two bottles of glue and two ABS materials. In addition to that Metropolia ordered more ABS and PLA material for printing.

Cubify Trio has a Wi-Fi adapter installed in it. Here we encountered the first problem with the printer. The issue was that we tried connecting to Wi-Fi with several computers, but none of the attempts was a success. Later we tried to connect the CubePro Trio to computer via USB cable. The computer could not install the proper drivers for the 3D printer, as CubePro Trio does not support the Vista operation system which the computer had. Lastly, we took a memory stick and still nothing worked. Later we tried to switch formats on the USB memory stick from NTFS to FAT. That resolved the memory stick problem.

The next obstacle we had was with the software of CubePro Trio. The software that was given in the USB memory stick was only a 3D design tool called Cubify Invent, but it was not a preparation software for the models to print. A preparation software for importing and manipulating digital 3D models for printing had to be found on the official webpage of the company. The CubePro software was hid in the Activation section of the official Cubify webpage.

Although the functionality of the software is actually quite primitive, it took an hour to figure out how it works. There are many different options. An engineering background helps to navigate through the software, but for a regular user it would bring difficulties. Even moving around the object gives hardship. It not only rotates around one axis, but around several ones, which leads to the user losing sight of the object. One helpful function in CubePro that differs from other software was Model Assembly. It can import a 3D model consisting of numerous parts as a group in which each piece could be altered without touching other pieces.

A gluing procedure was not mentioned anywhere besides on the glue bottle. There was a picture on the glue bottle stating how the glue should be applied on the platform. No instructions on the amount of the glue were given. After several test runs it became obvious that even two layers of glue will make the pilling off a difficult experience. For example it took about two hours to even lift one side of the 3D printed model from the platform. Figure 9 gives some examples.

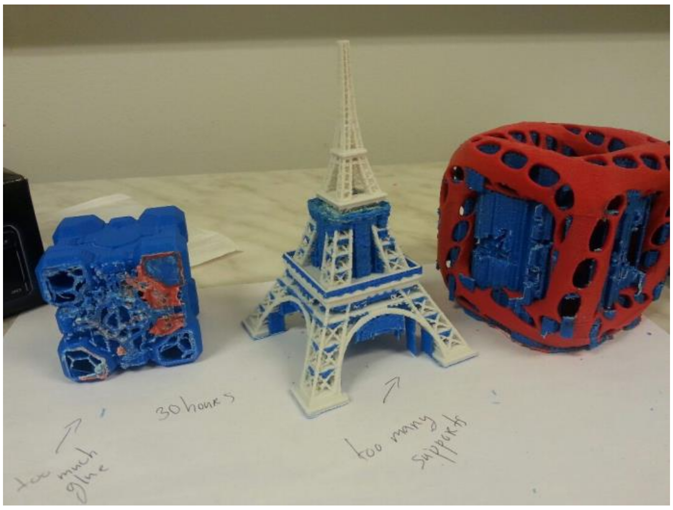

Figure 9. Three attempts to produce a proper 3D print.

After contacting the manufacturer, they explained that placing the platform under warm or hot running water would weaken the glue. Holding the build platform under warm tap water for a minute made it a little easier to release. The result can be seen in figure 10.

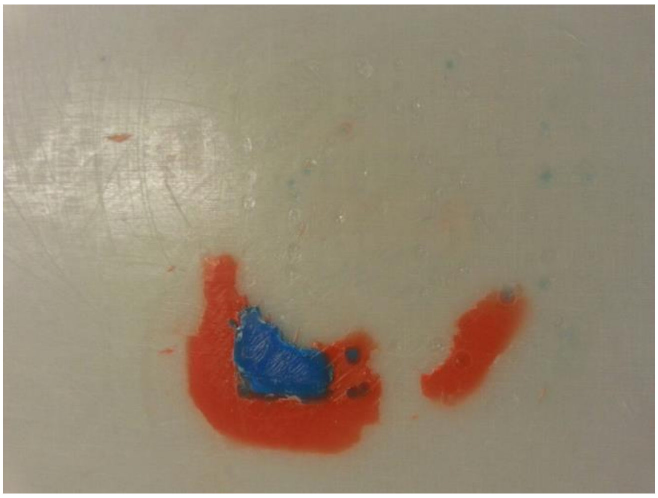

Figure 10. Parts of 3D printed object glued to the building platform.

One day it was noticed that CubePro Trio started making weird sounds. After inspecting the printer we found black residue on the worm gear screw of the machine. We had to clean the gear before continuing with future printings.

We expected that this may happen when we wanted to test out how the hollow objects of the machine prints from the inside and also cup shape models. Heart case was chosen for this attempt. The reason for this was as the ABS material color in honor of the International women's day (8^{th} March).

The print failed, as the machine did not print support structures properly. 3D printers do not have sensors to indicate if the printing process is going on properly. This was the reason why the machine continued to pour polymer on the build platform when there was no structure to pour onto it. Small hair shaped polymer flakes were everywhere inside of the machine as shown in yellow circles. Some of them even got into the worm screw shown inside the green square in figure 11.

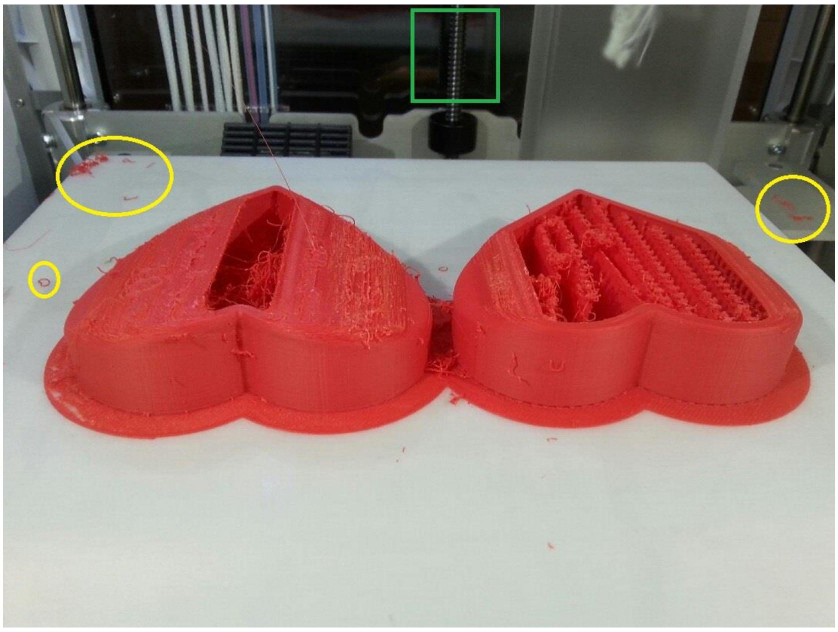

Figure 11. A failed 3D print of a bottom and a top case

The function of the worm screw is to lift the build platform up and down. After starting the printing process the worm screw lifts the build platform up for the gluing procedure. Next, the worm screw slowly drops the build platform for a 3D print. During the printing the worm screw constantly moves up and down. After the heart shape case accident the printer was cleaned from the inside, but some polymer flakes got onto the worm screw.

After the problem was acknowledged, the worm screw had to be cleaned entirely and greased afterwards. After the incident numerous calibrations were conducted.

Conclusion

Too many failures happened during the testing of the CubePro Trio. Proper instructions were not mentioned anywhere. After searching online an 89 webpage manual was found. The preparing for printing software for Cube Trio is a user's nightmare. Proper engineering knowledge is needed to operate with the software.

An advantage of the printer is that it could print ABS and PLA material simultaneously. The support structure is made with ABS and the object itself made from PLA. The removal of the support structures is done within an oven. The PLA melting point is 160 Celsius, while the ABS melting point is 105 Celsius. The oven is heated up to 120 Celsius for a couple of hours to let the ABS melt away. No pliers are required for this procedure. Only sand paper is needed for the finishing touch.

Fused Deposition Modeling or Stereolithography?

Choosing the better method out of fused deposition modeling and stereolithography is fairly simple. Fused deposition modeling takes longer to produce and a layer-by-layer shape could be seen with plain eyes. Blue glasses printed with Valmistaja 3000 and transparent glasses printed with Form 1+, as it is shown in figure 12. The method has its own advantages. One of them is that the method uses materials which are safe for the environment and which can be recycled and used later on. It is also much cheaper than the resin type of material. In addition, with this method one can pause the printing without cancelling the whole process. The same cannot be done with stereolithography.

Stereolithography, on the other hand, prints faster and more accurate objects. The disadvantage of it is that the post-production should be done entirely using rubber gloves. The toxic resin material and isopropanol alcohol could irritate the skin of the user, even if the user does not suffer from allergies. The vicinity of the 3D room should be ventilated constantly, as isopropanol alcohol fumes could lead to massive headaches, and generally it is not healthy to inhale them. Also the resin that was removed from the bottle and placed to a resin tank without being used for a month should be disposed of according to local regulatory guidelines.

Stereolithography is more of a commercial type of 3D printing, and fused deposed modeling is used more for personal 3D printing.

Figure 12. 3D printed glasses.

4.2 3D Scanner

Our small and developing 3D printing laboratory on the Leppävaara campus of Metropolia was introduced to 3D scanning through Sense 3D. The 3D scanner was my first interaction with a 3D handheld scanner or a 3D scanner in general. The Sense 3D scanner was designed and built by a company called Cubify. The design of the device is simple. Conducting scanning with the gadget is not demanding at all.

The scanner has two cameras on the right corner. One camera is for capturing the geometry of an object and the other is for capturing the color. [15]

Sense 3D uses the Sense software for scanning. Before starting scanning there are two options. One is for objects and the second one is for people. The options differ in the scanning area.

Scanning and Printing 3D Model

A scanned 3D object is a high polygon model that could be saved in three different formats: .OBJ, .STL and .PLY. An example of a scanned 3D model in the .STL file format can be seen in figure 13.

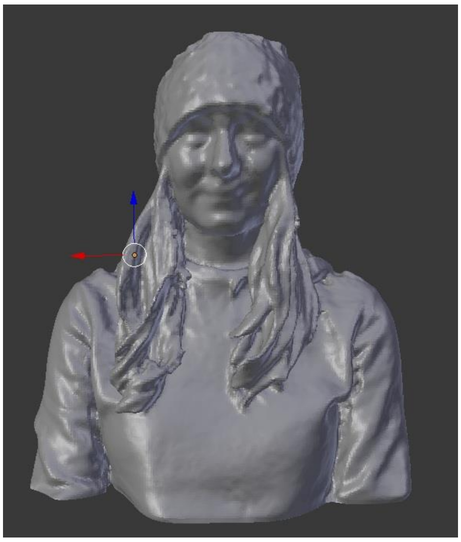

Figure 13. A scanned girl.

The 3D figurine was not altered in any way in the 3D modeling software. Figure 14 and 15 show two examples that were created with Form 1+ and Cubify Trio. Nail polish was used to color the piece printed by Form 1+ (see figure 14). CubePro Trio has a little deformity in the chin area, as can be seen in figure 15.

Figure 14. Print from Form 1+.

Figure 15. Print from CubePro Trio.

This shows that a model can be printed out straight after 3D scanning and that no 3D modeling software is needed.

Conclusion

The biggest issue with Sense 3D is that it has problems scanning shiny, transparent or dark objects. The reason behind this is that infrared light does not reflect from them. Numerous scanning attempts suggested that Sense 3D is great for human portrait scanning, but not for object scanning.

5 Guidance of Metropolia UAS Students

Cork Press

Kirill Kuvshinov, a Media Engineering student wanted to include the new 3D scanner and 3D printer of Metropolia in his course project work. The Museum of Technology in Helsinki have excellent exhibits, and the majority of them are behind protective glass or in a storage vault. The idea that he had was to scan a small historical piece and to 3D print it out, so that small kids could touch it and become more enthusiastic to learn about history and so that people with disabilities, like blind people, would finally have a chance to visualize an item with their hands.

Our first meeting with the employees of the Museum of Technology was a productive one. We went through the entire museum to find a technological piece of history to scan. My first idea for the scanning was to scan a 60-year-old tractor. The tractor was chosen only because of its location. It was placed in the center of the museum, so there was much space to go around it with the scanner. In addition to that the location was properly lightened. After negotiation with the project group a cork press from the 19th century was chosen (see figure 16). The simplicity of the object could be easily 3D printed out with a common 3D printer. The disadvantage of the cork press was that it was black in color and metallic (shiny). It was challenging to use 3D Sense to scan it.

Figure 16. 19th century cork press. Copied from Cork press [14].

3D Scanning the Object

The dark color of the object did not stop us on pursuing our goal. We arranged the second meeting at the museum after a couple of weeks. My audiovisual background helped me accurately prepare for our assignment. The team had to create an appropriate scanning area. I made a list of what was needed to be reserved from our Media lab. First we needed proper lighting, so two Lite panels for professional lighting had to be rent. Additionally two tripods for holding the scanner were borrowed. One tripod was used for stationary 3D scanning and another tripod was used for movable 3D scanning. Also a tripod dolly was needed for the movable tripod. A rotating plate was acquired for the cork press for professional 360 degree scanning. Exchange cord for powering up the scanner was rent. Finally, a duct tape was borrowed, as it always come handy.

Figure 17. Rotating the cork press slowly around the X axis.

At our second meeting at the museum the project group tried two methods of scanning. The first was the one when Sense 3D would be stationary and the 3D scanned object would be rotating only along the Z axis, as it can be seen in figure 17. The second method was letting the cork press stay still and moving the 3D scanner around it, as figure 18 shows. The scanning procedure could be monitored on the Sense 3D software. In the settings of the Sense 3D software we added a center point and frames per seconds. These adjustments would help us in the scanning. Frames per seconds (FPS) showed how much of the information the Sense 3D got from our position. If the FPS goes below 10 then one is losing the track of the object.

Using the two methods it was noticed that coming closer to the 3D scanned object would give better results. Even with this method we could only scan half of the cork press. After scanning 180 degrees around the object, the scanner loses the object from its sight and refuses to continue. The scanning was also tried with different lighting approaches. Lighting the cork press from behind, then from the side and lastly from the front. Sense 3D could scan one side of the cork press perfectly, but always lose track of the object when moving to the other side.

Figure 18. Keeping the cork press still and moving around it with 3D Sense.

Due to insufficient results and gaps in the 3D scanned model the measurements were taken of the cork press with a regular ruler, a piece of paper and a pen, as shown in figure 19. With the real-life measurements, the 3D scanned model could be fixed with 3D modeling software.

Figure 19. Taking notes of the cork press.

3D Model of Cork Press

With help from Vlad Kazakov, a Media Engineering student, a 3D model of the cork press was created. The cork press 3D model can be seen in figure 20. The 3D scanned model helped in modelling the 3D cork press. The handle and the base were created separately for printing.

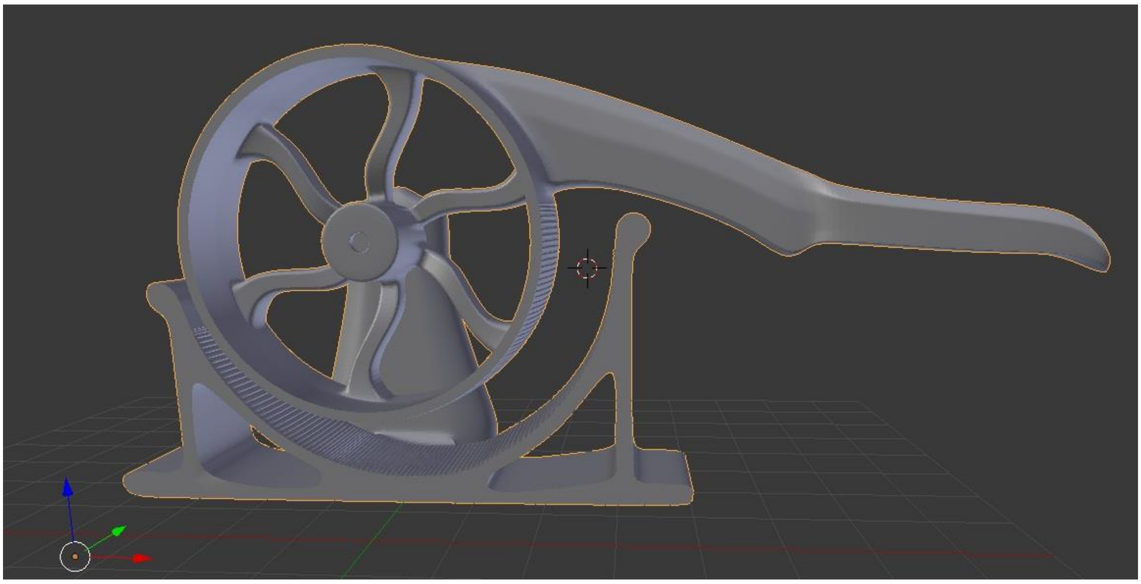

Figure 20. 3D model of the cork press

Cork Press with Form 1+

After receiving the resin from FormLabs the cork press was ready to print on Form 1+. The size was also an issue with Form 1+. For a first try it was scaled into half of the original size. The needed support structures were placed. The quality chosen was 0.2 mm and the material was grey 02. The printing time was approximately 6 hours.

During the printing it was noticed that the handle of the cork press was torn away from the wheel press, as it shows in figure 21. On later examination one of the spokes was not printed entirely.

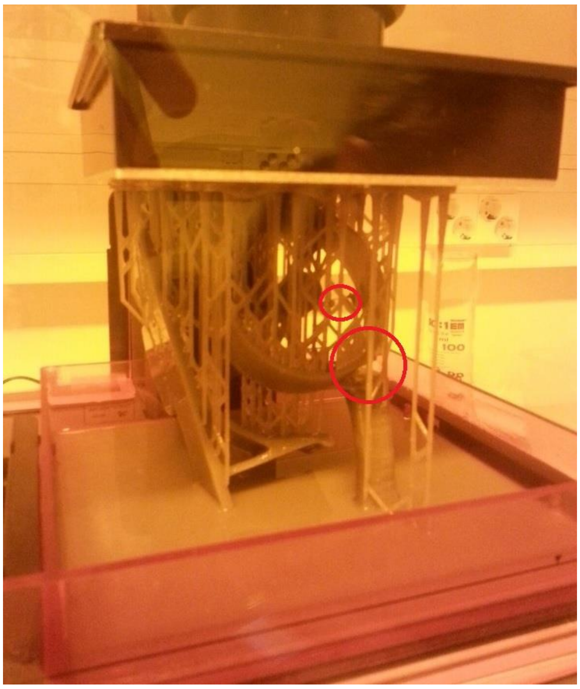

Figure 21. Bad print.

While removing the support structures more deformed areas of the cork press were found, as can be seen in figure 22. The holder on the base was poorly printed. One corner of the base was missing. The press wheel had a missing part.

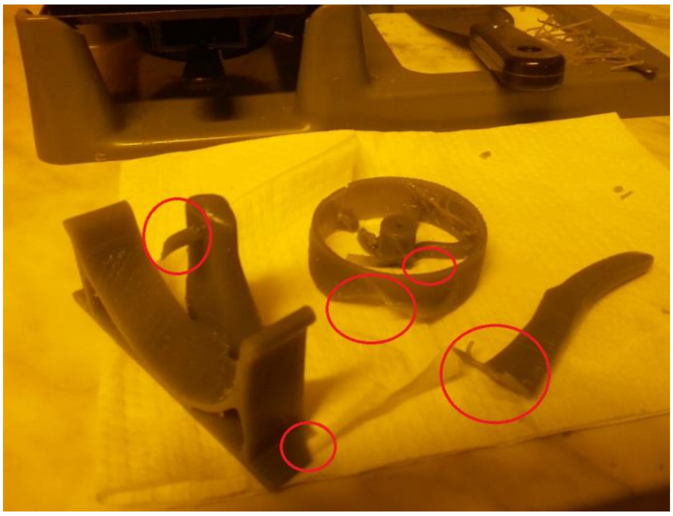

Figure 22. Three pieces of cork press.

This accident happened due to expired resin and a bad support structure. The resin outlived its expiration date. When the resin is not used within a month after it is poured into the resin tank, it starts to settle on the bottom of the resin tank. The laser beneath the printer cannot cure the resin and an ultimately a misshapen print is produced.

A second trial was conducted with newer resin and manually created support structures.

Figure 23. Splendid print of cork press from Form 1+.

The print succeeded, as it shows in figure 23. Due to the small size the print is going to be used as a showing piece, but not as a fully working cork press.

3D Printers of Finnish State Library Participating in the Project

The boom of 3D printing technology can even been seen in the libraries of Finland. For instance one of the most popular libraries of the Helsinki metropolitan area is the Sello library. It is located in center of Leppävaara, Espoo. [16]

One of my peers told me that the library's workshop now has 3D printers for use for the local audience. For my research I contacted Lauri Holopainen, the head of workshop in Sello library, via email. The question asked was: "What was the main cause for you to buy 3D printers for your workshop?" He answered the question with the following statement: "We wanted to offer the newest technology to our customers". [17] The library wanted to stay current with evolving 3D printing technologies. The library did not want to be left out.

The very first purchase of a 3D printer for the city library of Espoo was a standard FDM extruder printer Makerspace made by a Dutch company. Makerspace was introduced to the Tapiola library as an experiment. People showed interest in the 3D printer. Since then four libraries in the city of Espoo have acquired Makerspace for their libraries. Currently the Sello library has introduced several 3D printers at their workshop. The whole idea was to offer 3D printing to more people of the Leppävaara general public. [.17]

Figure 24. Ultimaker 2.

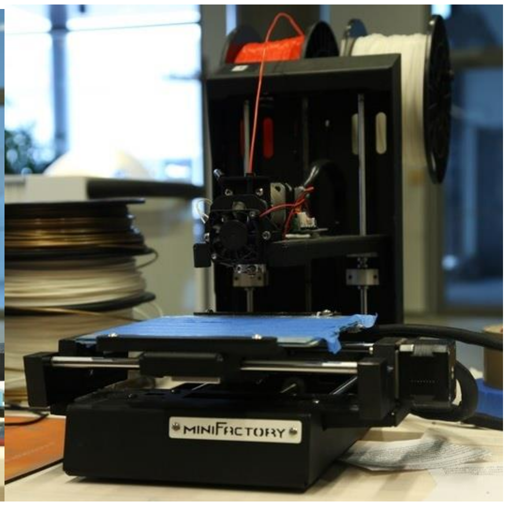

Figure 25. Minifactory

The models of 3D printers in the Leppävaara library are Finnish Minifactory and Dutch Ultimaker 2. Ultimaker can be seen in figure 24 and Minifactory in figure 25. They both use the FDM extruder method to produce 3D models. The material that is used consists of PLA and ABS which are standards for extruder 3D printers. The main reason for choosing this type of 3D printers was that they do not create any harmful smoke. Lauri Holopainen also stated:" We don´t know about other library workshops in other libraries. But I´m sure there will be a lot of them in the next ten years." [17]

The picture below depicts some samples which were printed on these 3D printers. The pieces were of a high quality (see figure 26).

Figure 26. 3D print gallery of the Sello library

As Form 1+ was too small to produce a proper print and our FDM printers were under calibration we decided to print the cork press in the Sello library. The Ultimaker 2 in the library was reserved. During the preparing process it was noticed that the cork press could not be printed out in its original size. The print was scaled down from the original size to 0.9 to fit in the Ultimaker 2, as it shows below in figure 27.

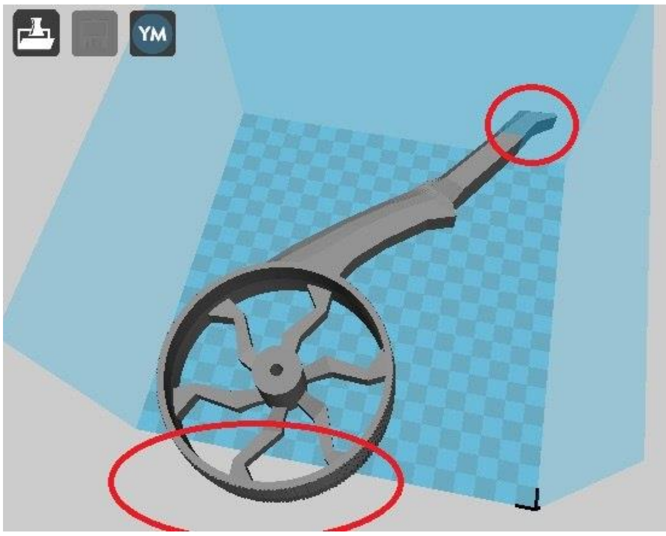

Figure 27. Cork press original size not fitting in to CURA.

Due to the opening hours of the library the printing had to be stopped in the evening and continued in the morning of the next day. The print time was almost was over twelve hours. The Ultimaker printing cork press of the library can be seen in figure 28. Moreover, unfortunately other library visitors are reserving 3D printers. This is the reason why the project will be on halt on till the end of the May of 2015.

Figure 28. 3D printing the handle of cork press with Ultimaker2.

Other Projects with Form 1+

Board Game

A Media Engineering student Pavel Ivanov approached me with an idea for an innovation project course. He wanted to create his own board game. His first task was to design and create a 3D model of dice with real life measurements. The printing size was small, and detailed stereolithography was chosen for this project, as it produces more accurate models than FDM printers.

A couple of days later Pavel Ivanov submitted the 3D file of dice. When importing the file into PreForm it was noticed that the measurements were wrong. They were too small for the dice. In PreForm the needed adjustments were made to the measurements. Before putting support structures for the dice it was detected that each die had no letter or number on one of the sides. The less detailed side should be always on the bottom, as the bottom gets most of the support structures. In the removing process of support strcutres the bottom could be damaged. To avoid this the less detailed side should be on the bottom. As the dice were one file they were imported into a 3D modeling software called Rhinoceros 5. There the necessary repairs were done to the dice and the fixed dice file was exported to the .STL format.

The result is shown in figure 29 and figure 30. The result was pleasing. The printed dice did not require any polishing.

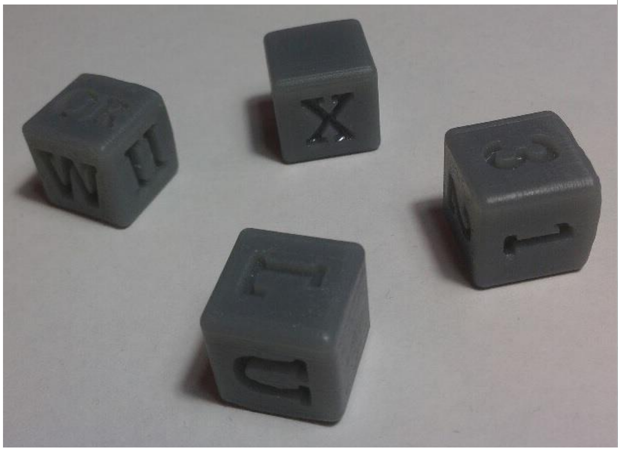

Figure 29. Four die.

Figure 30. Octahedron die.

Water Meter Cover

A student of Building Services Engineering, Aleksi Väisänen wanted me to help him to 3D print out a water meter cover. This was for a course about innovations. The student had a model with real measurements in millimeters. The model was prepared for a print by using PreForm. The simplicity of the model did not require any support structure, though previous experience showed me that cup shape models will be poorly printed out because of center gravity. This happens because the weight of the object is not supported during the long printing time.

The water meter cover can be seen in figure 31.

Figure 31. Water meter cover.

6 Design and Manufacturing

My last assignment for the final year project was to design and produce a lamp. The idea was to go through concept, design and print on my own. For several weeks three concepts for the lamp were considered.

6.1 Concepts and Design

A creative desk lamp was planned. The first idea was to manufacture an astronaut's helmet with a separate visor. The second idea was to build a face desk lamp the mouth and the eyes of which could be opened and closed. Both ideas can be seen in figure 32.

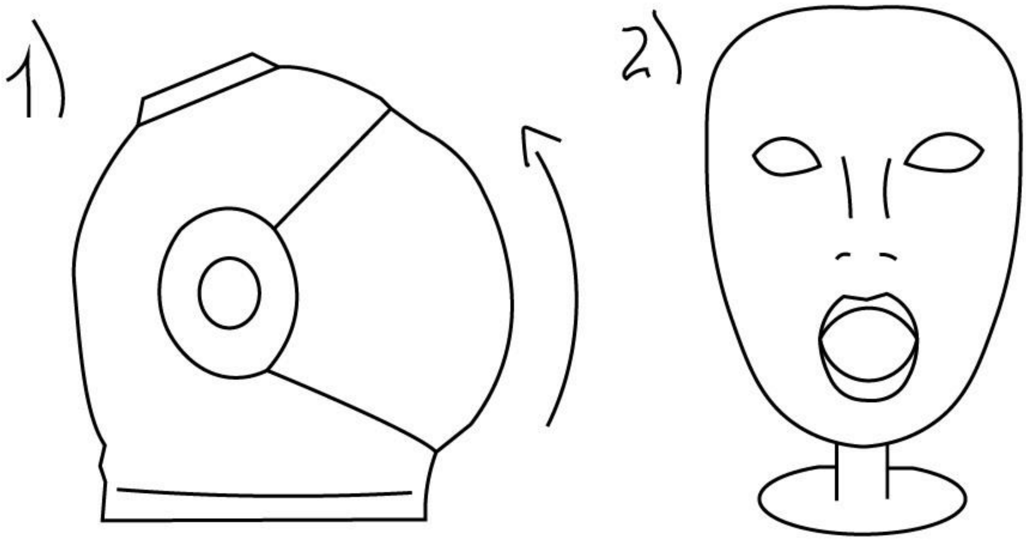

Figure 32. Two concepts for the desk lamp.

The final idea was to create a sitting cat. The light would come from the face of the cat and the wiring would go through the cat's tail. The idea was inspired by online research. Cats have a huge popularity on the internet. [18]

A 3D model of the cat was created with the Blender 3D modeling software. Which is an open-source software. The 3D model of the cat is shown in figure 33.

The technical structure of the cat can be seen in figure 34. The wiring would go through the cat's tail into the lamp socket. The lamp socket will be held by a holder which is placed in the cat's throat. The light bulb will be lighting just above the mouth from the inside.

Figure 33. 3D model of the cat lamp

The lamp was designed so that the head of the cat would look downwards. The light shines in one direction like an Anglepoise lamp.

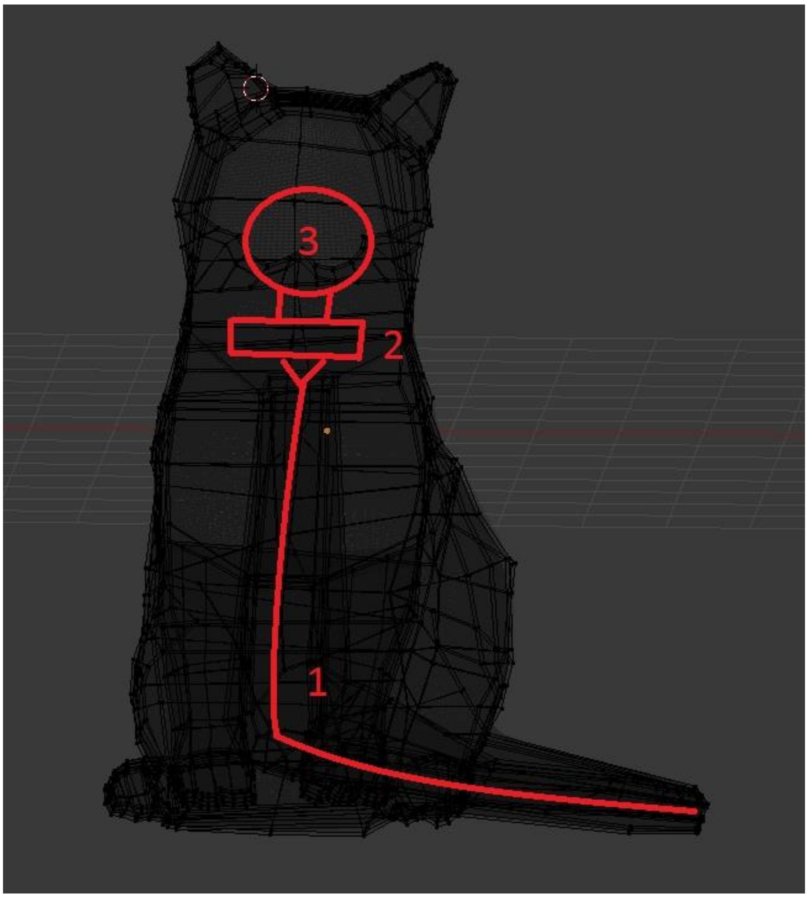

Figure 34. 1. The wiring 2. The lamp socket 3. The light bulb

6.2 Printing and Final Result

Before printing a bigger piece a test run was arranged. The selected cat's height was 6 cm. The selected thickness of the print was 0.2 mm, as the cat does not have any detailed features. Black resin was selected for this experiment. It took around 50 minutes and 30 milliliters of resin to create this lamp.

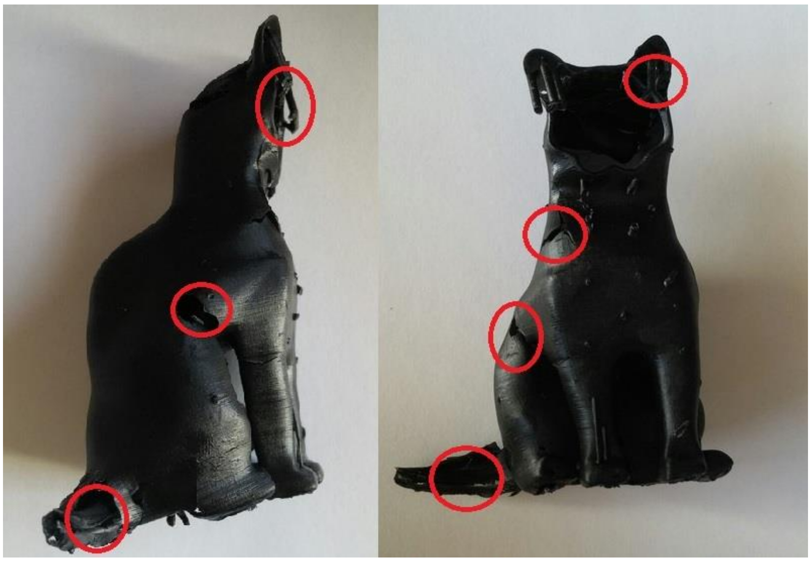

Figure 35. Damaged areas circled in red.

The first print was not a success, as it shows in figure 35. The print failed due to the thin shell of the lamp. While removing the support structure, the outer shell gave in and broke. The holes were formed in the process. For this reason the cat was remodeled to be solid from the inside. After remodeling a second print was rearranged.

For the second print it took Form 1+ approximately 7 hours to print. The same settings were applied as for the previous print. The cat lamp was resized to the maximum amount of resin of the resin tank 200 milliliters. The measurements of the printed cat are 5 cm in depth, 10 cm in length and 7.5 cm in width. In total 190 milliliters of clear 02 resin was spent.

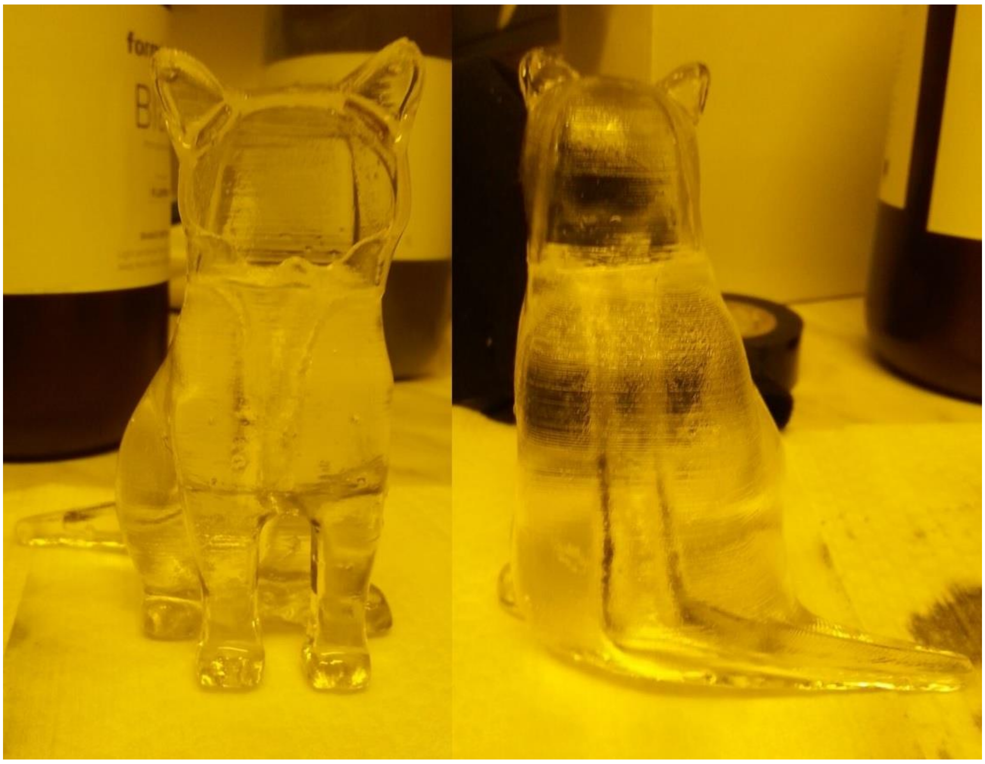

Figure 36. 3D printed cat lamp

The second printing went smoothly. Thanks to the manually placed support structure removing process was not hard. No polishing was required, as shown in figure 36. Because of the solid structure the lamp took the maximum amount of resin from the resin tank. If a bottle of resin costs 150 dollars and its volume is one liter, then one fifth of that is 30 dollars. Essentially, 30 dollars were spent to create this small lamp. Cost-wise this is a bad manufacturing decision. The needed lamp should be twice of the size. The model would demand more support structures. Essentially half a liter of resin would be required for proper production.

With the last print size of the lamp, the first impression was that the lamp is only suitable for small light-emitting diodes (LED) and nothing bigger than that. For a desk lamp, which would work as directional light, LEDs are not enough. As a result, the cat lamp became a transparent figurine of display.

Later on when an electric potential 2.5 volt lamp of 1.5 cm in length was found, it was decided to continue the lamp project, but in smaller scale. The small lamp was soldered to wires of negative and positive electrical polarity. Energy was supplied by connecting a nine-volt battery to the other end of the wiring. The project succeeded. The end result can be seen in figure 37.

Figure 37. A small working lamp.

7 Conclusions

The aim of this final year project was to estimate the effectiveness of 3D printing in small-scale production today.

Several prints demonstrated that 3D prints should be properly prepared before actual printing. Moreover, the printing process should be monitored, as the printers do not have sensors to detect whether the printing has failed or not. My 3D printed cat lamp project showed that 3D printing right now is an expensive manufacturing process. Producing a small lamp almost took a full working day, or eight hours. Time is used for preparing the print, printing and post-production. In the end, the result was a small solid lamp printed in the lowest resolution possible. In total 3D printing means that not only the material was wasted, but also human resources, materials such as isopropanol alcohol, and electricity for the printer and the UV lamp. In the cork press project the 3D scanner did not capture the geometry of the cork press properly. The 3D model of the cork press had to be repaired and finally remodeled. These procedures took days. The entire project took months to produce a size cork press half of the original cork press. Moreover, the cork press is not operable because of the small size.

The project suggest, that currently 3D printing is only good for small-scale production, for example, in prototyping. In rapid manufacturing 3D printing is still at its beginning stage. The layer-by-layer shape is the biggest weakness of 3D printed products. It takes hours and sometimes days to produce one model. Conventional methods for manufacturing of, for instance, plastic plates or metallic buckets take seconds to minutes. The process takes place on the conveyor, so multiple pieces are created each moment. 3D printing is years away from a mass-scale production.

Still, 3D printing is evolving enormously in today’s world. For eight months I have studied the subject of 3D printing. During this time I have seen a great leap forward with 3D printing. The great solution for the time issue that arises in the 3D printing field was continuous liquid interface production. The material is becoming cheaper. New companies are established in North America and Europe, offering cheaper resin and polymer for 3D printers.

Finally, at the moment 3D printing is mostly suitable for single prints and not manufacturing production. It is a rapidly developing technology, which gives many opportunities for future research, work, and innovation.

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